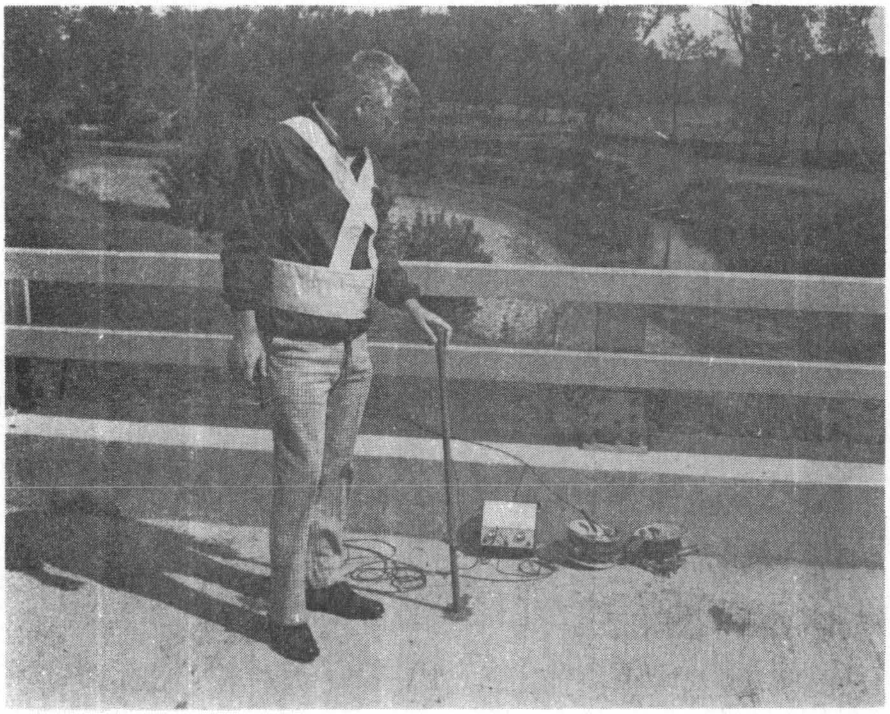
DETECTION OF STEEL CORROSION IN BRIDGE DECKS AND REINFORCED CONCRETE PAVEMENT



DEPARTMENT OF TRANSPORTATION
IOWA

Iowa Highway Research Board
Project HR-156
Final Report

Highway Division
May 1977

DETECTION OF STEEL CORROSION IN BRIDGE DECKS AND REINFORCED CONCRETE PAVEMENT

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by
Vernon J. Marks

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Iowa Department of Transportation
Highway Division
Office of Materials
Ames, Iowa 50010
515-296-1447

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ABSTRACT

The Iowa Department of Transportation initiated this research to evaluate the reliability, benefit and application of the corrosion detection device. Through field testing prior to repair projects and inspection at the time of repair, the device was shown to be reliable.

With the reliability established, twelve additional devices were purchased so that this evaluation procedure could be used routinely on all repair projects. The corrosion detection device was established as a means for determining concrete removal for repair. Removal of the concrete down to the top reinforcing steel is required for all areas exhibiting electrical potentials greater than 0.45 Volt.

It was determined that the corrosion detection device was not applicable to membrane testing.

The corrosion detection device has been used to evaluate corrosion of reinforcing steel in continuously reinforced concrete pavement.

DETECTION OF STEEL CORROSION IN BRIDGE DECKS AND REINFORCED CONCRETE PAVEMENT

INTRODUCTION

Bridge deck deterioration remains a major maintenance problem for highway departments. The corrosion of the reinforcing steel is considered to be the primary contributor to this problem.

The P.C. Concrete initially acts as an environment that prevents corrosion of the reinforcing steel. This protection is dependent upon the quality of the concrete. Deicing salts used in winter maintenance introduce chlorides into the concrete and destroy this initial protection. The chloride content sufficient to permit steel corrosion within the concrete is referred to as the corrosion threshold. This corrosion threshold is dependent on the cement content of the concrete(1) and would be 1.4 lb./cu.yd. for concrete in Iowa bridge decks (710 lbs. of cement/cu.yd.). If the chloride content of the concrete reaches this level, the protection has been destroyed and if sufficient moisture and oxygen are present, corrosion will begin.

The rust formed by corrosion occupies considerably more volume than the parent steel and this results in a force that exceeds the strength of the concrete. This causes the concrete to crack horizontally at the top steel and develop a delamination. Water infiltration and subsequent freezing, along with the traffic, create even greater pressures which cause spalling.

Iowa has developed a low slump, dense concrete bridge deck resurfacing method for restoration of these deteriorated decks. This program began more than twelve years ago as a patching procedure. It is now a nationally accepted method of bridge deck resurfacing.

In the early use of Iowa's method of P.C. patching and deck resurfacing, the only means for determining the area of concrete to be removed to the top reinforcing steel was by sounding. Using a chain drag, hammer, or other tapping device, the delaminated area was drawn on the surface to show the contractor the area for concrete removal. The problem with this procedure was that delamination and spalling would occur later around the periphery of the removal area.

In the fall of 1970, the Federal Highway Administration gave a demonstration in Iowa of a corrosion detection device developed in a California research project. From this demonstration, sufficient interest was generated to initiate a research project in the testing and application of the device.

PROBLEM

The problem was the application of the corrosion detection device to repair procedures in Iowa. At the time of the FHWA demonstration, the method had not been fully tested. Iowa was second on the demonstration visits out of requests from approximately 40 states. The device had not been fully tested so the demonstration team was gathering information along with demonstrating the technique.

The device is a non-destructive testing procedure that measures the electrical potential between the steel reinforcing and the adjacent concrete. Part of the application of the device is to be able to correlate readings with known conditions of the steel.

OBJECTIVES

The objectives of this research were:

(1) To establish the reliability of the device as an aid in locating deck areas needing repair.

(2) To assign quantitative values indicating the types and extent of repair necessary.

(3) To evaluate the various types of overlays, waterproofing membranes and patching operations.

(4) To determine the usefulness of the technique on continuously reinforced concrete pavement.

EQUIPMENT

Two corrosion detection devices were built by purchasing commercially available components and making minor electrical connections for assembly. The device (Figures 1 and 2) consists of a high quality voltmeter, a "half-cell" probe of copper-copper sulfate and two spools of light gage insulated electrical wire.

These first two devices were funded through the research project and were assembled at a cost of $550 each. When the project was initiated a high quality voltmeter was considered essential. Because this was research, there was an extra effort to assure that a voltmeter with adequate capability was purchased. The voltmeters for these first two devices had more capabilities and quality than needed. Much of the expense for these first two devices was due to a more expensive voltmeter than necessary.

The components for the device shown in Figure 1 are those currently being used in the inspection of repair projects. Presently, the device can be assembled for about $275. A more detailed description of the separate components and the sources where the Iowa D.O.T. has purchased them is given in Appendix A. Today's approximate prices are also given.

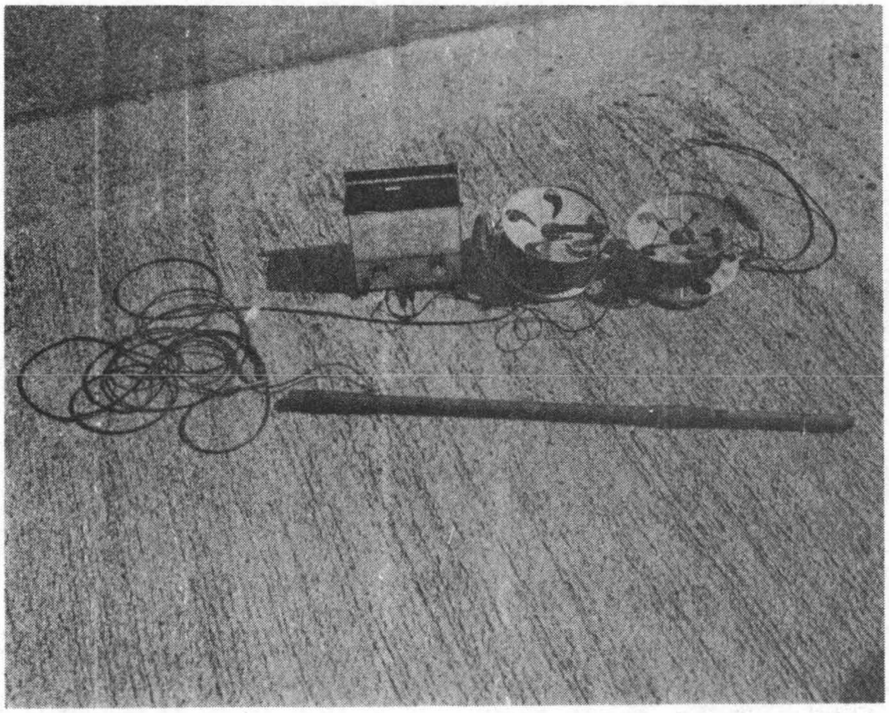


Figure 1. The Components for the Corrosion Detection Device

1. A High Quality Voltmeter
2. A Copper-Copper Sulfate Probe
3. A 300 ft. Reel of Insulated Wire (Red)
4. A 125 ft. Reel of Insulated Wire (Black)

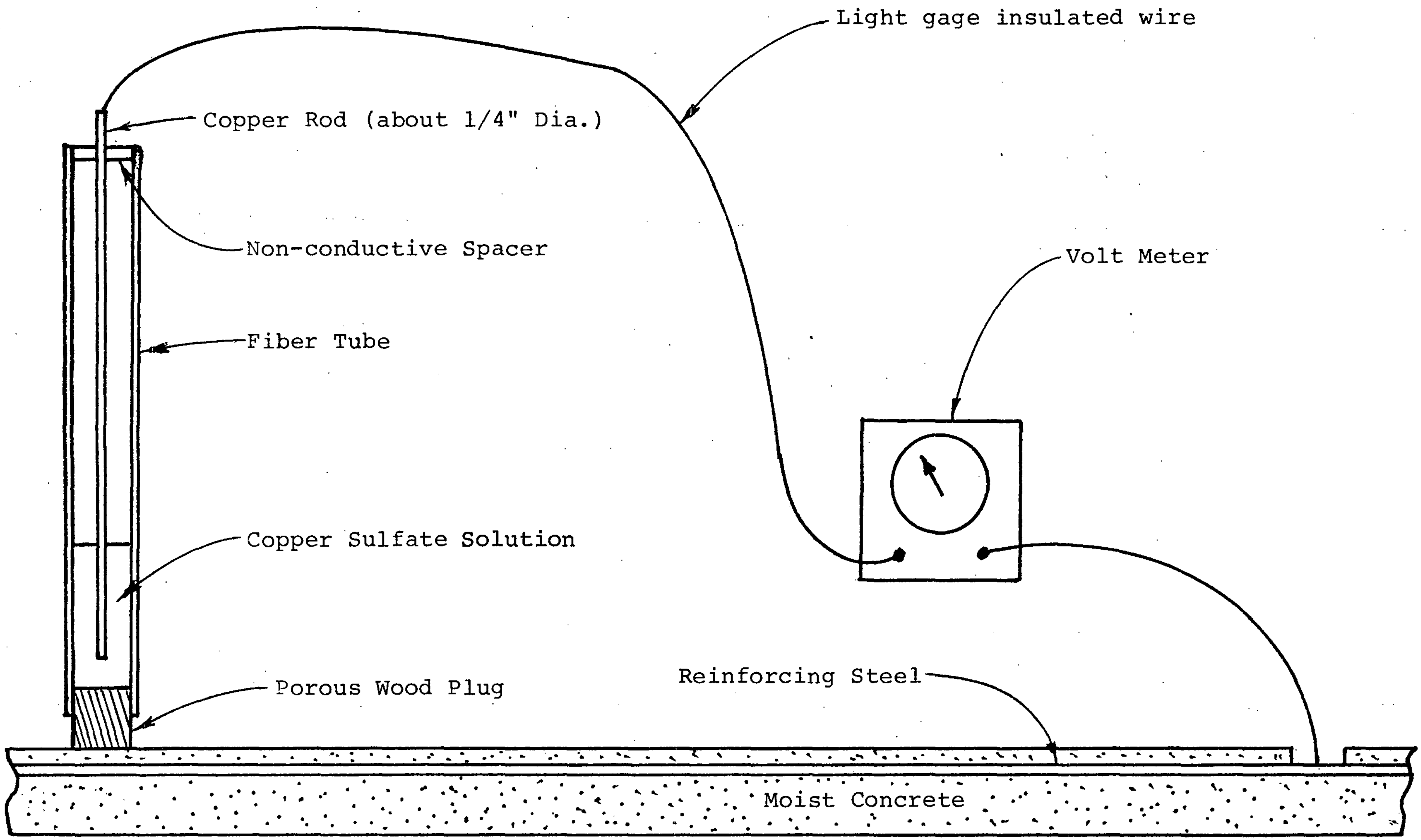


Figure 2 CORROSION DETECTION DEVICE

TEST PROCEDURE

The test procedure adopted was essentially the same as that of the FHWA demonstration team. The copper rod suspended in the saturated copper sulfate solution of the "half-cell" probe produces a constant potential that is electrically connected to oppose the galvanic "half cell" of the bridge deck. This is done by connecting one lead of the voltmeter to the reinforcing steel and the other to the probe. Each location on the bridge is wetted to provide good electrical contact between the probe and surface. A detailed procedure "Test Method No. Iowa 1008-A" is included in Appendix B. In the original procedure, the connection to the reinforcing steel was normally made through either the metal expansion assembly or a bar chair under the deck. Experience has shown that a poor connection between these and the mat of reinforcing steel will yield erroneous readings. The present recommended procedure is to connect directly onto the reinforcing steel.

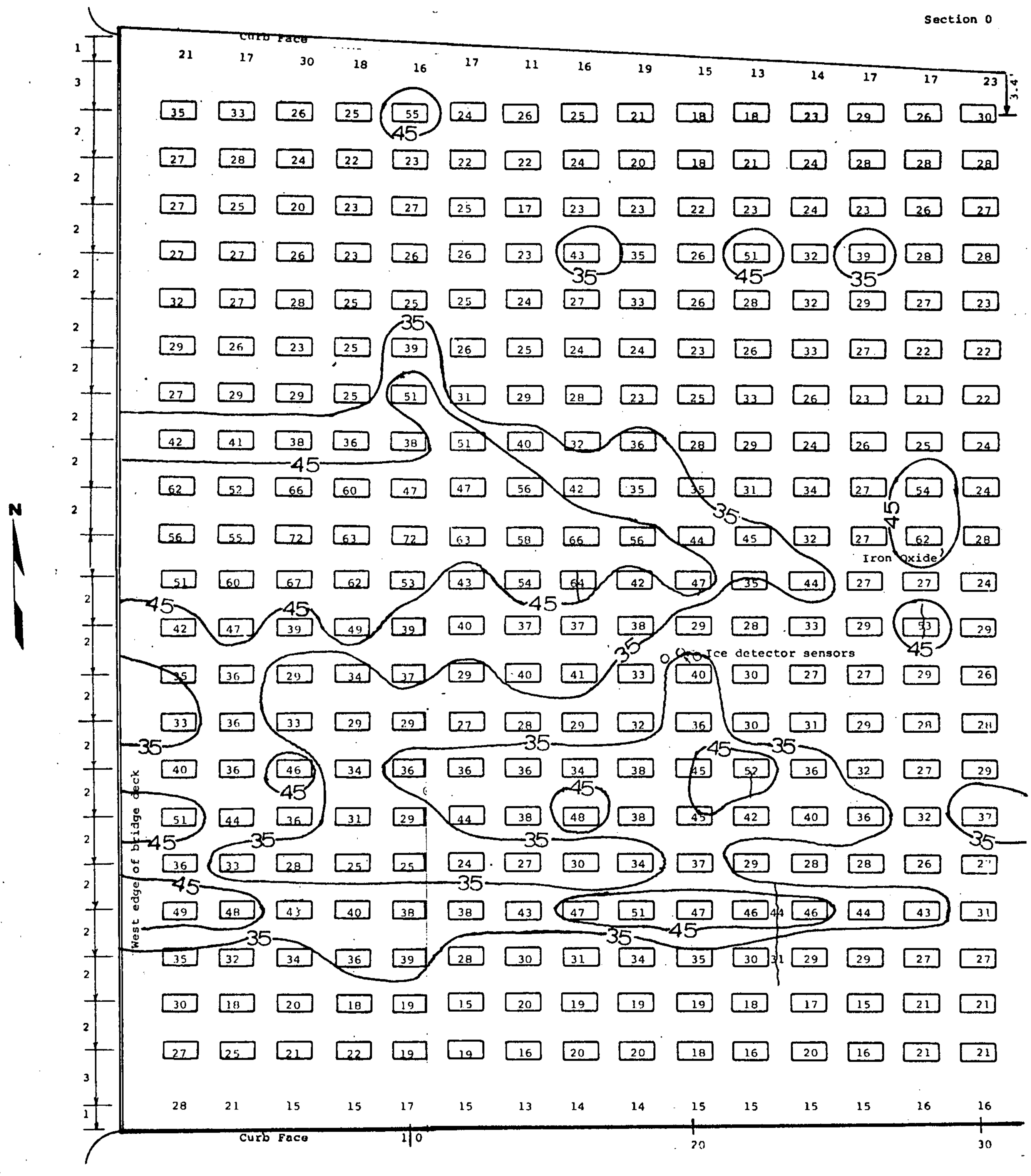
EVALUATION

The device was developed by the State of California and much of the subsequent evaluation has been by California. The resultant potential from the corrosion detection device is a negative value, but the potential is commonly used without notation of the minus. Potentials in this report will be referred to as a numeric voltage value and the minus sign will not be used. In studies by California,(2) it has been shown that half-cell potential values greater than 0.35 volt to the copper-copper sulfate probe generally exhibit active corrosion. Values between 0.30 and 0.35 Volt are inconclusive, but values less than 0.30 volt show the steel to be passive or chemically inhibited from corrosion. These values do not measure the amount of chloride that is present at the reinforcing steel, but only indicate if it is sufficient to permit active corrosion.

To determine the reliability of the device, corrosion testing was performed on a number of bridge decks in Iowa that were scheduled for repair. Electrical potential contours (Figure 3) were plotted for some of these decks. After the concrete removal in preparation for resurfacing, a visual observation of the corrosion of the reinforcing steel showed a relationship to corrosion readings.

In one case, corrosion detection contours were laid out for a selected area on a bridge deck. At that time, there was essentially no visible deterioration (Figure 3) of the deck. There was, however, one definable area where corrosion detection readings were greater than 0.45 volt. A visual inspection of this same area one year later showed considerable spalling (Figure 4). This further supports the relationship of the potential and active corrosion.

Bridge deck resurfacing in Iowa has been relatively successful even prior to the introduction of the corrosion detection device. Prior to 1974, evaluation of bridge decks being considered for repair and the determination of the extent of the repair, were based almost entirely on the amount of spalling and delamination present. In 1974, corrosion detection readings were adapted to be used with sounding methods to determine areas for concrete

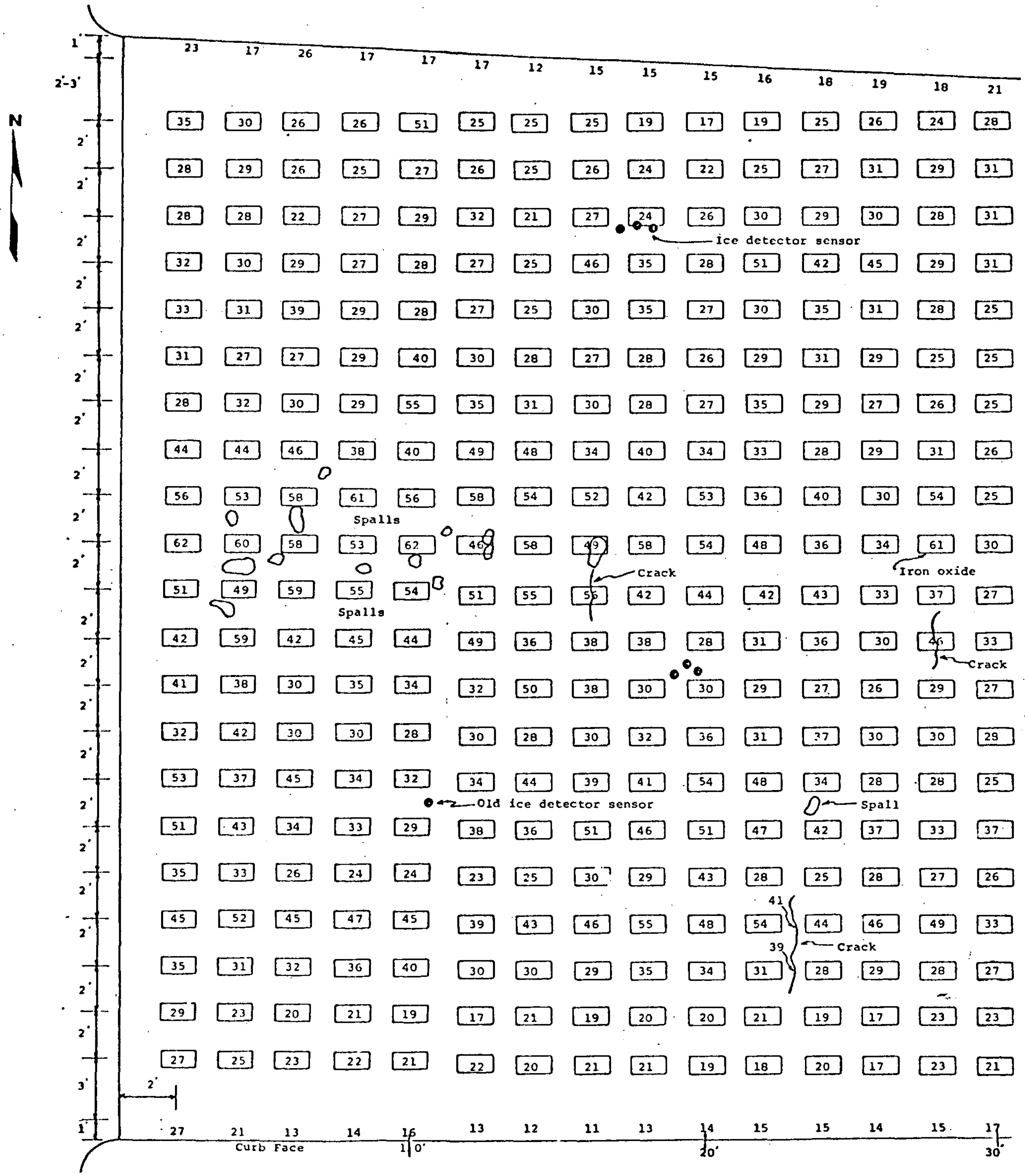


Location Story County US 30 over US 69 (EBT)

Date May 3, 1972 Air Temp. 65°

Figure 3. Electrical Potential Contours. There were a few isolated cracks, but no spalling at the time of this survey.

Section 0



Location Story County US 30 over US 69 (EBT)

Date June 6, 1973

Figure 4. Extensive spalling of an area that had shown electrical potentials greater than 0.45 volt one year earlier

removal. It was decided that all areas exhibiting potential values greater than 0.45 volt should have the concrete removed down to the top reinforcing steel. This decision was based on past repair experience and the conclusion that cracking and spalling were eminent for these areas. This corrosion detection data was to be obtained for use in design of the repair, as well as being used at the time of construction if all of the concrete above the reinforcing steel was not removed. This criteria of 0.45 volt was established and the method of incorporating it into a project has been by a note on the plans. The plans note that the engineer shall conduct a survey at the time of construction and all areas with potentials greater than 0.45 volt shall be included for Class A repair. Class A repair requires removal of the concrete to below the top reinforcing steel. The 0.45 value and the note on the plans remain as present practice.

Twelve more corrosion detection devices were purchased to implement this new program. A training program was initiated for maintenance and construction personnel in the proper operation and testing procedure. The field personnel, using the twelve units purchased in 1974, have routinely conducted testing of the bridge decks prior to design. They have also provided the testing required at the time of construction. The device has been adopted as a reliable aid in locating deck areas needing repair.

This device is being used as one method of post construction evaluation. A program of systematic testing of areas on certain designated bridge decks that have been repaired using the Iowa method of restoration is being conducted. Even after resurfacing with P.C. concrete, the device will yield voltage readings that may be used to show areas of active corrosion.

The units have been used for more than six years with relatively few problems. Some problems have been encountered in obtaining a good connection to the reinforcing steel. Another problem has been in proper maintenance of the copper-copper sulfate probe. The copper sulfate solution must be saturated to yield a standard potential. There has been at least one instance where a diluted solution gave erroneous results. There have been a number of cases where the external fiber tube of the probe had to be replaced. This was due to breakage either from improper handling or permitting the copper sulfate solution to freeze. The voltmeters are periodically checked and there has been one instance where recalibration was necessary. These are generally the only problems encountered with the device.

It was determined that the principle of the corrosion detection device was not applicable to testing of membrane systems and, therefore, it was never used for this purpose. A similar test was developed on the basis of resistivity for the evaluation of membranes.

Highway Research Project HR-1004, "Corrosion of Steel in Continuously Reinforced Concrete Pavement" was conducted using the device to determine if there was active corrosion. The research was conducted in 1974 on fourteen different Interstate pavement projects. Readings were taken directly over a reinforcing bar at transverse cracks and at midpoints between the transverse cracks. Electrical potentials were considered on the basis of the 0.35 volt criteria based upon the California research, but it has not been proven that this value is applicable to pavement. This 1974 research did not indicate a serious corrosion problem but results did suggest that corrosion could become a concern of the future. This project did demonstrate the usefulness of the corrosion detection device on continuous reinforced concrete pavement.

CONCLUSIONS

The conclusions that can be gained from this research are:

1. The corrosion detection device is a reliable aid in locating deck areas needing repair.

2. The requirement for removal of areas showing a potential numerically greater than 0.45 volt has improved the bridge deck restoration program.

3. The corrosion detection device is relatively free of maintenance.

4. The device is not applicable to the evaluation of membrane systems.

5. The device is useful as a technique for evaluating continuously reinforced concrete.

RECOMMENDATIONS

It is recommended that research be conducted to evaluate the present condition of areas on bridge deck restoration projects where the concrete was not removed and readings were in the 0.35 to 0.45 volt range at the time of construction. This data should be used to reevaluate the use of the 0.45 volt value and consider the use of a 0.35 volt criteria that would require a greater amount of concrete removal.

REFERENCES

1. Clear, K.C. and Hay, R.E., "Time-to-Corrosion of Reinforcing Steel in Concrete Slabs - Volume 1: Effect of Mix Design and Construction Parameters," Report No. FHWA-RD-73-32, Federal Highway Administration, Interim Report, April 1973.
2. Stratfull, Richard F., "Corrosion Autopsy of a Structurally Unsound Bridge Deck" Highway Research Record No. 433, 1973.

Appendix A

Sources and Costs of Corrosion Detection Device Components

SOURCES AND COST OF CORROSION DETECTION DEVICE COMPONENTS

Sources where the Iowa D.O.T. has obtained the individual components and today's approximate costs.

1. Voltmeter - Simpson Model 313

   Approximate Price - $150.00

2. Collins Copper Copper-Sulfate reference electrode

   Harco Corporation
   4600 East 71st Street
   Cleveland, Ohio 45216
   and
   Agra Engineering
   551 South Quaker Avenue
   Tulsa, Oklahoma 74120

   Approximate Price - $40.00

3. Reel w/300 ft. #18 Stranded Wire (red)

   Approximate Price - $50.00

4. Reel w/125 ft. #18 Stranded Wire (black)

   Approximate Price - $35.00

   Agra Engineering
   551 South Quaker Avenue
   Tulsa, Oklahoma 74120

Appendix B

Method of Test for Determining the Corrosion Potential of Bridge Deck Steel by the Electrical Potential Method

IOWA DEPARTMENT OF TRANSPORTATION
HIGHWAY DIVISION

Office of Materials

METHOD OF TEST FOR DETERMINING THE CORROSION POTENTIAL OF BRIDGE DECK STEEL BY THE ELECTRICAL POTENTIAL METHOD

Scope

Corrosion of reinforcing steel is caused by an electric current flowing from the rebar at one point (the anode) into the bar at another point (the cathode). During active corrosion an electrical (potential) difference exists between the anode and the cathode.

When this electrical potential difference is -.35 volts or greater (-.40 or -.50) there is a high probability that active corrosion of the reinforcing steel is occurring. The corrosion product (rust) exerts tremendous forces on the concrete resulting in spalls.

This test method describes the procedure to be used in determining the corrosion level of reinforcing steel in a concrete bridge deck when utilizing a copper sulfate reference electrode (half cell).

Procedure

A. Apparatus

1. Voltmeter--Simpson Model 313-2
2. Copper - copper sulfate probe
3. Wire
4. Water*, pail and squeeze bottle
5. Hammer and chisel
6. 50' or 100' tape
7. Marking keel
8. Data and layout sheet

*(Wetting agent necessary in water when using through asphaltic concrete.)

B. Project Information

The following information should be recorded on the data and layout sheet. See example on page 3.

1. Type and location of bridge
2. Design No.
3. Maintenance No.
4. Date Tested and by whom
5. Layout showing location of each test point
6. Location where ground wire was attached to deck steel
7. Electrical potential readings
8. North arrow
9. Longitudinal dimension required for skew

C. Voltmeter Calibration

The following steps must be completed prior to initiating the test procedure.

1. With the circuit selector switch to "OFF", check to see that the pointer is set on the "0" mark at the left side of the scale. If the pointer is not on "0", set the pointer to "0" by turning the screw in the center of the meter.
2. Check battery by setting circuit selector switch to "BATT". Pointer must be read to the right of the "BATTERY OK" mark on meter face.
3. Turn range switch to 1 (one) volt.
4. Turn the circuit selector switch to "+DC", connect the positive lead and black wire from the meter together and turn the knob marked "ZERO" clockwise or counterclockwise until the pointer rests over the "0" mark at the left side of the scale.
5. Connect positive lead from meter to red wire connected to the probe, and the black wire from meter to the black wire connected to the deck steel.

D. Test Procedure

1. Lay out 4' x 4' grid pattern on bridge deck. Be sure and measure the test points very accurately, since the test points may have to be relocated at a later date. Additional readings may be required due to skew angles.
2. Wet each point to be read and allow to soak a minimum of 10 to 15 minutes.
3. Connect the black wire (ground) to a steel expansion plate or drain which is tied into the steel reinforcing mat of the deck being

tested. If this is not possible, connect onto the steel support chairs located under the bridge deck.

4. Check to be sure that copper-sulfate fills the probe and connect the red wire to the probe.

5. Take readings by placing the probe on the point to be tested and record each reading on the data sheet.
The reading should be taken after the needle stops fluctuating.

CAUTION: Always let the pointer settle before taking readings. If the pointer continues to waver, there may be a bad connection or interference such as power lines in the area. The maximum reading possible is .78 v. If a reading above .78 v. is obtained, the meter is probably not set correctly.

E. Copper-Sulfate Solution

The copper-sulfate solution for the probe is available through the Materials Laboratory Receiving Office. However, if field mixing of the solution becomes necessary, copper-sulfate crystals or powder can be obtained through chemical supply stores. The test requires using a saturated copper-sulfate/water solution. The amount of copper-sulfate needed for saturation varies with water temperature. Copper-sulfate must be added with vigorous stirring until a few crystals appear in the solution. The amount used should be above 14% by weight of the amount of water used.

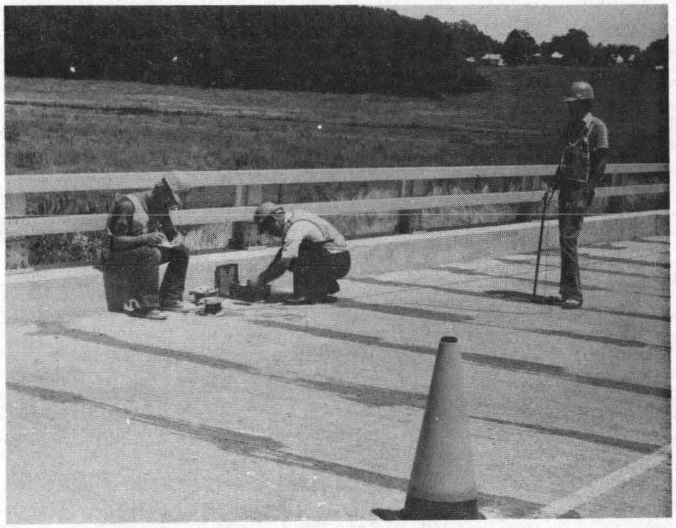


Figure 1

Corrosion Detection Test

N ←

Bridge Continued On Next Sheet

X

2'

27	29	23	29	25	24	21	41	31	30	27	24	24	32	23	20
36	41	41	31	33	35	33	42	31	29	31	21	26	34	26	22
31	26	35	30	27	29	29	40	37	30	32	27	27	34	26	24
35	26	33	28	27	30	27	41	45	29	32	27	25	33	26	27
21	23	27	38	28	30	34	33	39	44	23	36	30	29	26	21
23	18	19	20	14	17	17	28	19	20	11	20	14	16	28	42

2'

South End Of Bridge

Type and location of bridge Steel Bm/Gird-Cherokee Co. on U.S.59 Design No. 1934

Maintenance No. 1868.1S059 Date tested 11-5-76 Tested by Richard Renaud

Remarks Over Grey Creek X-marks where ground wire was attached